Predictability and Dynamics of Geophysical Fluid Flows

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LONG-TERM GOALS

The long-term goal of my research in this project is to improve our ability to predict environmental conditions using dynamical models.

OBJECTIVES

The central objective of my research in this project is to understand the mathematical and physical connections between the bred-growing-mode and singular vector techniques recently developed for numerical weather prediction, the Lyapunov vectors and exponents of dynamical systems theory, and instability theories of geophysical fluid dynamics. My intent is to gain insight into fundamental mathematical and physical aspects of predictability in unstable (irregular, chaotic) continuous systems.

APPROACH

I am using a combination of analytical and numerical methods to study a variety of mathematical models of geophysical fluid flows.

WORK COMPLETED

Graduate student Christopher Wolfe, who is supported by this grant, and I have completed and published a study of a strongly nonlinear baroclinic wave-mean oscillation and its time-dependent normal-mode instabilities in a high-dimensional geophysical fluid model (Samelson and Wolfe, 2003). This model is a two-layer, quasi-geostrophic, numerical channel model with 48 along-channel and 40 cross-channel modes in each layer, for a total of 3,840 degrees of freedom. This study included a novel application of the efficient Newton-Picard solver PDECONT developed by Lust et al. (1998). We have also completed the study of a number of related nonlinear wave-mean cycles, for which we have computed all of the unstable and stable linear disturbance eigenvalues and eigenmodes.

This project has also provided partial support for several other efforts, including research on Lagrangian motion in coastal ocean circulation (Kuebel et al., 2003; Kuebel Cervantes et al., 2003), and studies of the coastal lower atmosphere and comparisons of model and scatterometer wind stress fields (Perlin et al., submitted). Wolfe was a Student Fellow at the 2003 Woods Hole Summer Program in Geophysical Fluid Dynamics, where he worked with C. Cenedese on laboratory models of eddy generation by flow over variable topography (Wolfe, 2003).

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RESULTS

The complete Floquet spectra computed for strongly nonlinear cycles show structure similar to that found in the weakly nonlinear case (Samelson, 2001): a neutral wave-dynamical mode (Figure 1), several weakly damped or unstable wave-dynamical modes (Figure 2), several rapidly damped wave-dynamical modes (Figure 3), and many modes that are damped at a rate roughly equal to the Ekman friction timescale. The latter are often dominated by small-scale features that are advected along the channel in opposite directions by the mean flow in each layer (Figure 4). This behavior is in marked contrast to the wave-dynamical modes, which are coherent between the layers and are quasi-stationary in these flows with nearly zero mean barotropic motion. Inclusion of higher-order viscosity induces additional scale selectivity in the frictionally damped modes.

IMPACT/APPLICATIONS

The primary potential future impact of these results is on the design and use of ensemble forecasting techniques for the prediction of oceanic and atmospheric conditions.

RELATED PROJECTS

This work formed part of the ONR Predictability DRI. The coastal meteorological research is partially supported by the ONR project “COAMPS Simulations of the Coastal Atmosphere” and the NSF project “COAST: Coastal Ocean Advances in Shelf Transport.” The research on dynamics and predictability is related to the NSF ITR project “Spatio-Temporal Complexity and Nonlinear Dynamics of Coastal Ocean Flows” (R. Samelson, J. Allen, and G. Egbert, Co-PIs).

SUMMARY

The results described above open a new perspective on the analysis of the evolution and predictability of oceanic and atmospheric flows, by showing that techniques previously restricted to highly simplified models can be extended and adapted for models that are sufficiently complex that they can be expected to provide substantial insight into geophysical fluid motion. This perspective is yielding new results relevant to instability theory and to ensemble forecasting methods for environmental prediction. Participation in this ONR-sponsored work has enhanced my institution by increasing its visibility in the research community, stimulating interaction among institutional colleagues, and supporting a graduate student specifically interested in the problems addressed in this work.

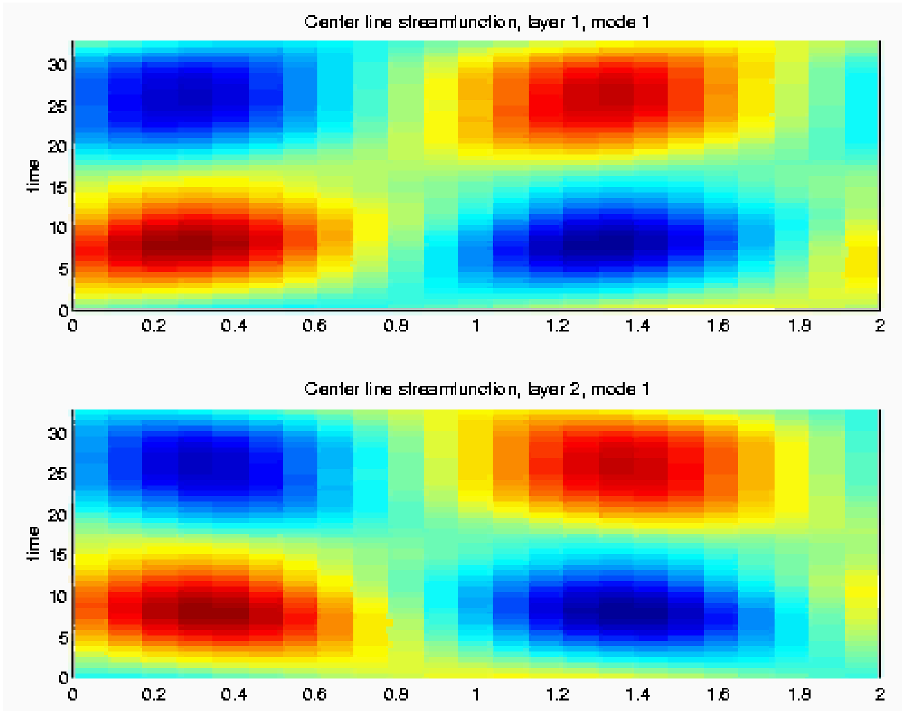

Figure 1. Contours (red-positive; blue-negative; absolute amplitude arbitrary) of streamfunction in layers 1 (upper panel) and 2 (lower panel) along the center of the periodic zonal channel vs. time (one oscillation period) for neutral linear mode of a nonlinear wave-mean oscillation

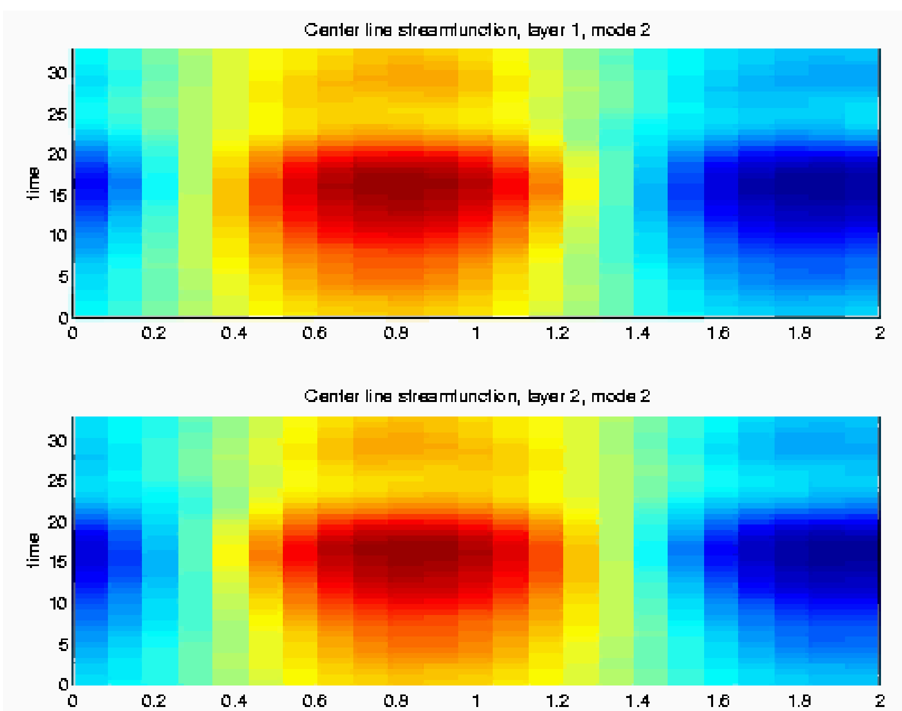

Figure 2. As in Fig. 1, but for the least stable linear mode of the nonlinear wave-mean oscillation. The mode is normalized by its exponential growth factor, so the contours show the time-periodic structure function.

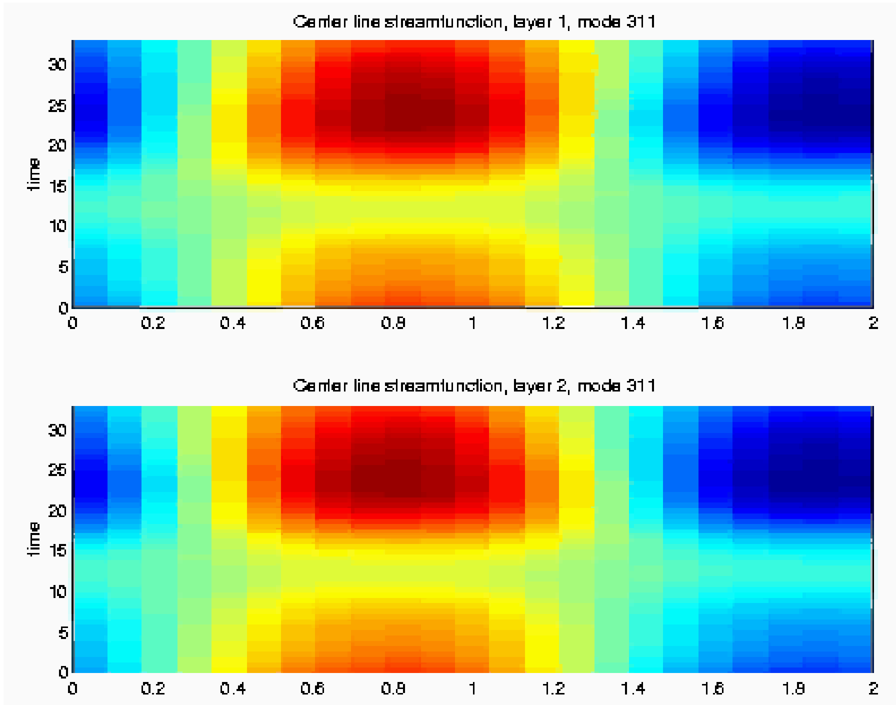

Figure 3. As in Fig. 2, but for the corresponding rapidly-damped wave-dynamical linear mode of the nonlinear wave-mean oscillation. Note the approximate time-reversal symmetry relative to the mode in Fig. 2.

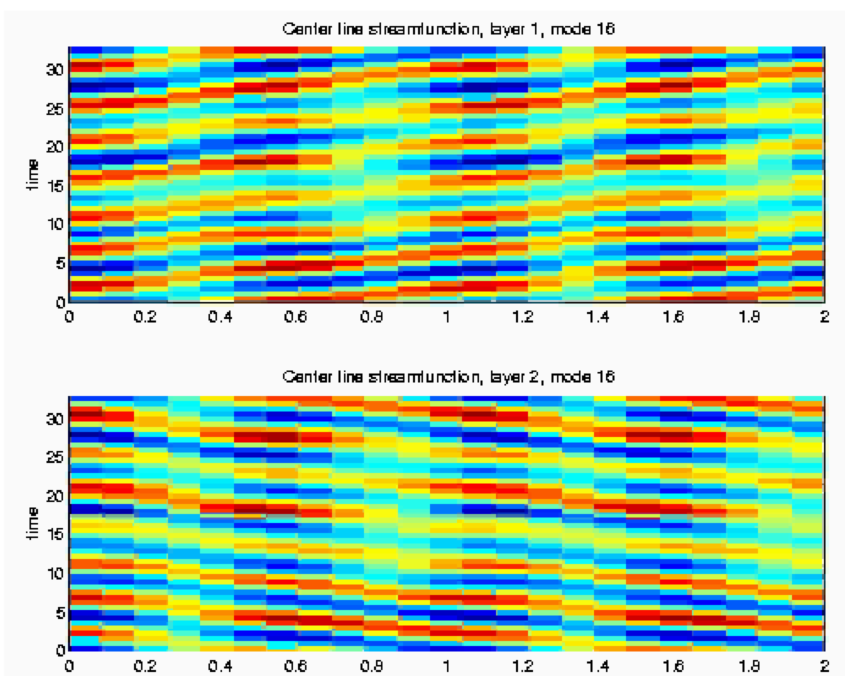

Figure 4. As in Fig. 2, but for an advective, frictionally damped linear mode of the nonlinear wave-mean oscillation. The mean flow is to the right in layer 1 (upper panel) and to the left in layer 2 (lower panel).

REFERENCES

Lust, K., D. Roose, A. Spence, and A. Champneys, 1998. An adaptive Newton-Picard algorithm with subspace iteration for computing periodic solutions. SIAM Journal on Scientific Computing, 19, 1188-1209.

PUBLICATIONS

Kuebel, B. T., J. S. Allen, P. A. Newberger, and R. M. Samelson, 2003. A modeling study of Eulerian and Lagrangian aspects of shelf circulation off Duck, North Carolina. Journal of Physical Oceanography. [in press]

Kuebel Cervantes, B. T., J. S. Allen, and R. M. Samelson, 2003. Lagrangian characteristics of continental shelf flows forced by periodic wind stress. Nonlinear Processes in Geophysics, submitted.

Perlin, N., R. M. Samelson, and D. B. Chelton, Scatterometer and model wind and wind stress in the Oregon-California coastal zone. Monthly Weather Review, submitted.

Samelson, R. M., and C. L. Wolfe, 2003. A nonlinear baroclinic wave-mean oscillation with multiple normal-mode instabilities. Journal of the Atmospheric Sciences, 60, 1186-1199. [published]

Wolfe, C. L., 2003. Eddy generation by flow over variable topography: some experiments. In *Proceedings of 2003 Summer Program in Geophysical Fluid Dynamics*, Woods Hole Tech. Rep., to appear. [in press]

AWARDS

Christopher L. Wolfe, Student Fellowship, Woods Hole Summer Program in Geophysical Fluid Dynamics